

Resummation of Transverse Momentum and Mass Logarithms for Heavy Quarks

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Collaborators:

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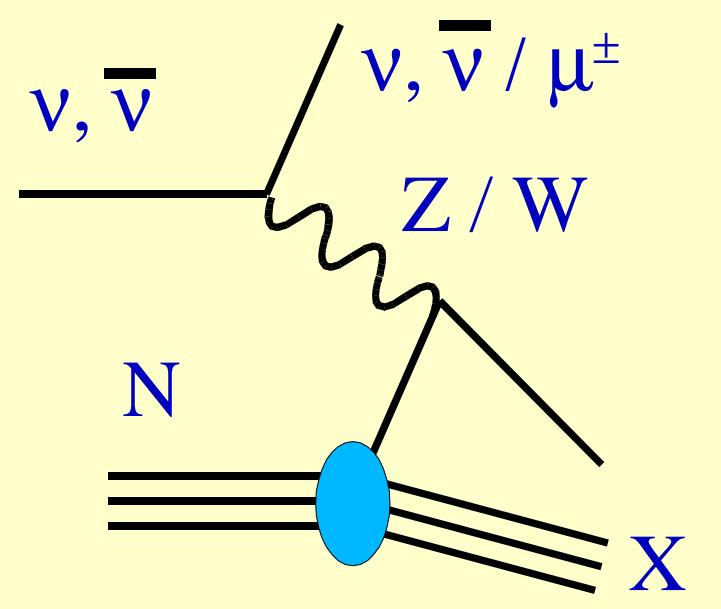
*Let's start with
an example*

Electroweak Mixing Angle Measurement

NuTeV Result: $\sin^2 \theta_W^{(on-shell)} = 0.2277 \pm 0.0031 (stat) \pm 0.0009 (syst) \dots$

Standard Model Fit: $\sin^2 \theta_W^{(on-shell)} = 0.2227 \pm 0.0004$ (*LEP EWWG*)

A discrepancy of 3σ



Paschos-Wolfenstein Relation:

$$R^- \equiv \frac{\sigma(\nu_\mu N \rightarrow \nu_\mu X) - \sigma(\bar{\nu}_\mu N \rightarrow \bar{\nu}_\mu X)}{\sigma(\nu_\mu N \rightarrow \mu^- X) - \sigma(\bar{\nu}_\mu N \rightarrow \mu^+ X)} = \frac{1}{2} - \sin^2 \theta_w$$

Contributions to Experimental Uncertainty

SOURCE OF UNCERTAINTY	$\delta \sin^2 \theta_W$	δR^ν	$\delta R^{\bar{\nu}}$
Data Statistics	0.00135	0.00069	0.00159
Monte Carlo Statistics	0.00010	0.00006	0.00010
TOTAL STATISTICS	0.00135	0.00069	0.00159
$\nu_e, \bar{\nu}_e$ Flux	0.00039	0.00025	0.00044
Energy Measurement	0.00018	0.00015	0.00024
Shower Length Model	0.00027	0.00021	0.00020
Counter Efficiency, Noise, Size	0.00023	0.00014	0.00006
Interaction Vertex	0.00030	0.00022	0.00017
TOTAL EXPERIMENTAL	0.00063	0.00044	0.00057
Charm Production, Strange Sea	0.00047	0.00089	0.00184
Charm Sea	0.00010	0.00005	0.00004
$\sigma^{\bar{\nu}}/\sigma^\nu$	0.00022	0.00007	0.00026
Radiative Corrections	0.00011	0.00005	0.00006
Non-Isoscalar Target	0.00005	0.00004	0.00004
Higher Twist	0.00014	0.00012	0.00013
R_L	0.00032	0.00045	0.00101
TOTAL MODEL	0.00064	0.00101	0.00212
TOTAL UNCERTAINTY	0.00162	0.00130	0.00272

Largest model uncertainty
arises from
charm production
and $s(x)$



s and s-bar difference can
have large effect

... relative uncertainty is
reduced for combination

TABLE I. Uncertainties for both the single parameter $\sin^2 \theta_W$ fit and for the comparison of R^ν and $R^{\bar{\nu}}$ with model predictions.

Our ability to make accurate

measurements and extract

$\sin^2\theta_w$ and $s(x)$ relies on

precision* calculations

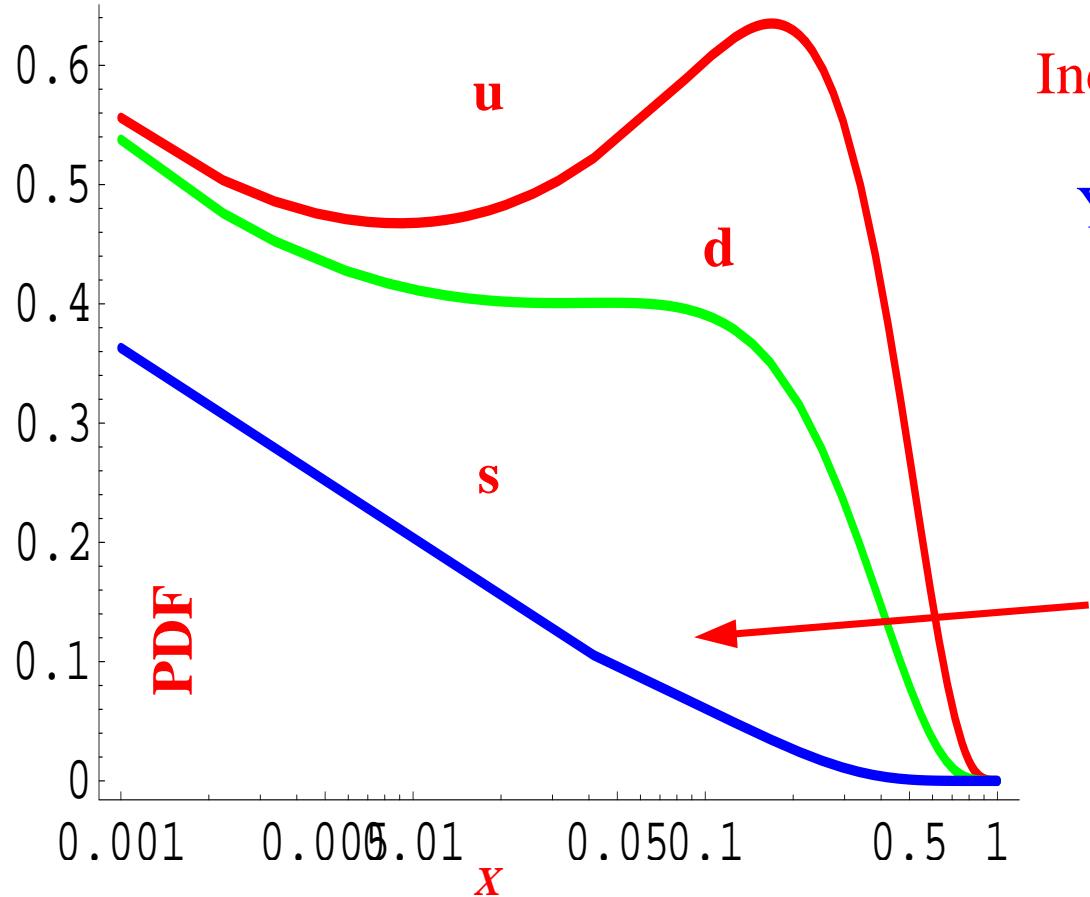
*Higher orders & resummation

Where does the $s(x)$
distribution come from?

What is the mechanism
for Charm production?

Is he going to have any answers, or just questions?

Where does $s(x)$ come from???



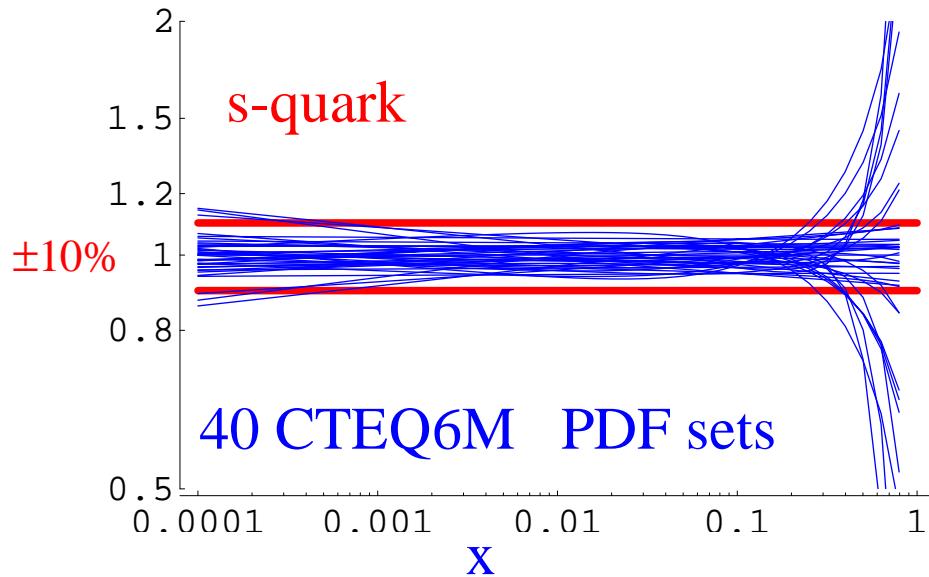
Inclusive Structure Functions:

Yield $s(x)$ in combination

Must extract
 $s(x)$
from under
other PDF's

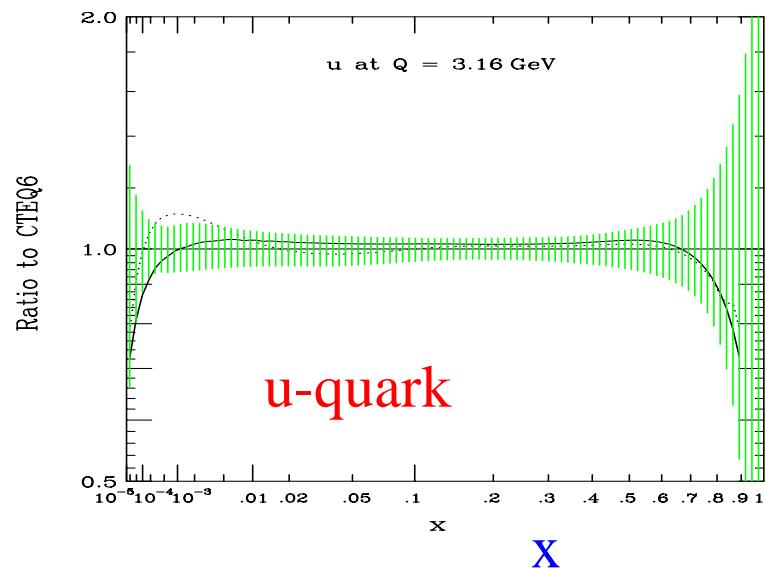
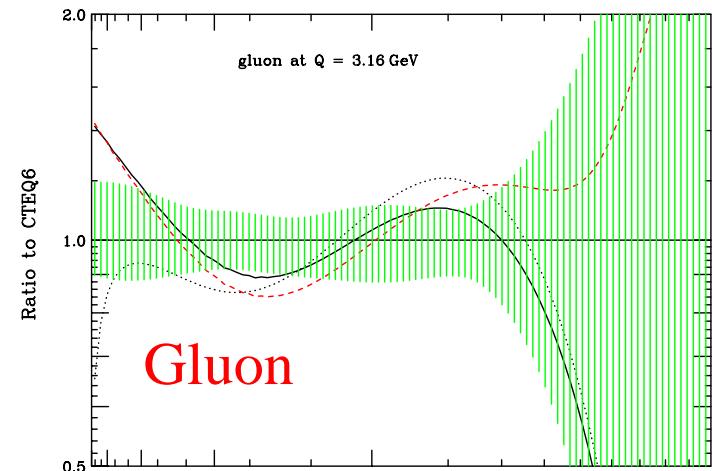
$$F_2^{CC} = x(u + \bar{u} + d + \bar{d} + s + \bar{s} + c + \bar{c})$$

What is relative uncertainty on $s(x)$???



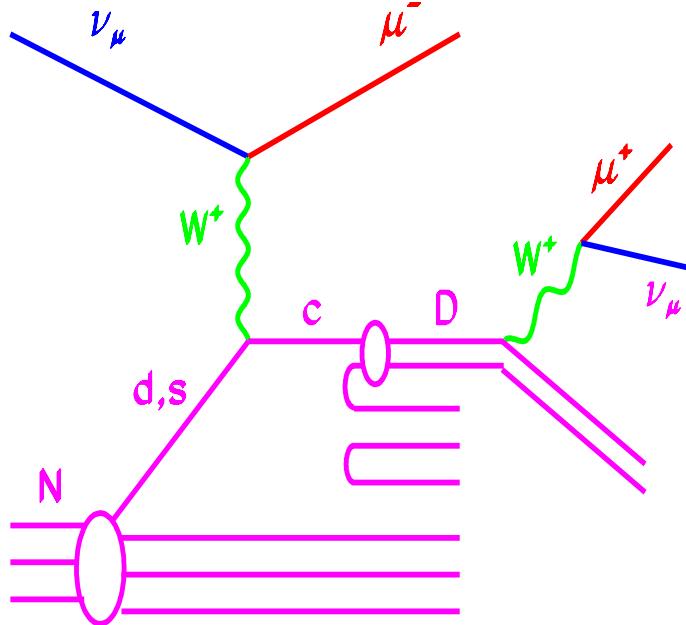
Presently, $s(x)$ is tied to
u-bar and d-bar via kappa:

$$s(x) = \bar{s}(x) = \kappa \frac{\bar{u}(x) + \bar{d}(x)}{2}$$



We can do better!

Dimuons are ideal signal of s(x)



di-muon	NuTeV	CCFR	Combined
Neutrino	5012	5030	10042
Anti-Nu	1458	1060	2518

- * High stats & high precision data
- * Best constraints on strange quark

$$\frac{d \sigma_{\mu^\pm \mu^\mp}^+}{dx dy} = \int d\Gamma d\Omega \frac{d \sigma_{\mu^\mp c}^+}{dx dy d\Gamma} \otimes D_c(\Gamma) \otimes \Delta_c(\Omega)|_E \Big|_{\mu^\pm > 5 \text{ GeV}}$$

Di-muon cross-section

Charm Production cross-section

Fragmentation Function

Decay Distribution

Parameterization of $s(x)$ at Q_0

$$s(x, Q_0) \equiv \bar{s}(x, Q_0) = a_0 x^{a_1} (1-x)^{a_2} \times f(a_3, a_4, a_5; x)$$

Constrained fit: $\{a_0\}$ free

Mixed fit: $\{a_0, a_2\}$ free

Free fit: $\{a_i\}$ free

Global Fit including ν -DIS Di-Muon Data

χ^2 / DOF	CTEQ6M	Constrained	Mixed	Free
CCFR Nu	1.02	0.85	0.79	0.72
CCFR Nu-bar	0.58	0.54	0.59	0.59
NuTeV Nu	1.81	1.70	1.55	1.44
NuTeV Nu-bar	1.48	1.30	1.15	1.13
BCDMS F2p	1.11	1.11	1.11	1.11
BCDMS F2d	1.10	1.10	1.10	1.11
H1 96/97	0.94	0.95	0.94	0.94
H1 98/99	1.02	1.03	1.03	1.03
ZEUS 96/97	1.14	1.14	1.14	1.15
NMC F2p	1.52	1.50	1.51	1.49
NMC F2d/F2p	0.91	0.91	0.91	0.91
NMC F2d/F2p $\langle Q^2 \rangle$	1.05	1.07	1.06	1.03
CCFR F2	1.70	1.71	1.81	1.88
CCFR F3	0.42	0.42	0.44	0.42
E605	0.82	0.82	0.82	0.83
NA51	0.62	0.61	0.52	0.52
CDF ℓ Asym	0.82	0.83	0.82	0.82
E866	0.39	0.40	0.39	0.38
D0 Jets	0.71	0.65	0.70	0.67
CDF Jets	1.48	1.48	1.48	1.47
TOTAL	2173	2144	2142	2133

Total of 1991 data points

CTEQ6: J. Pumplin, et al., JHEP 0207:012,2002

Reasonable χ^2 values
(CTEQ6 did not fit di-muon data)

More parameters,
lower value of χ^2

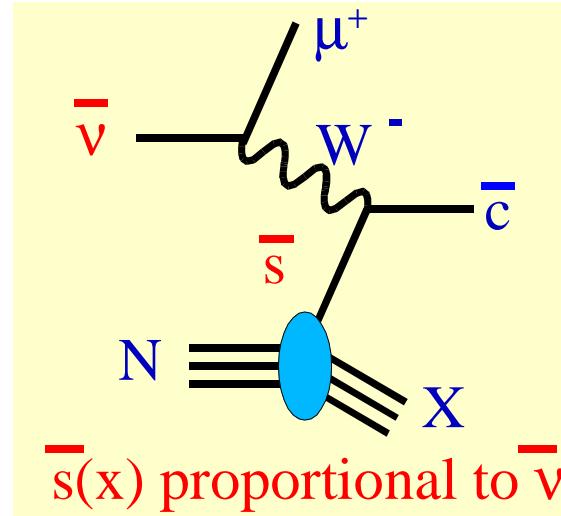
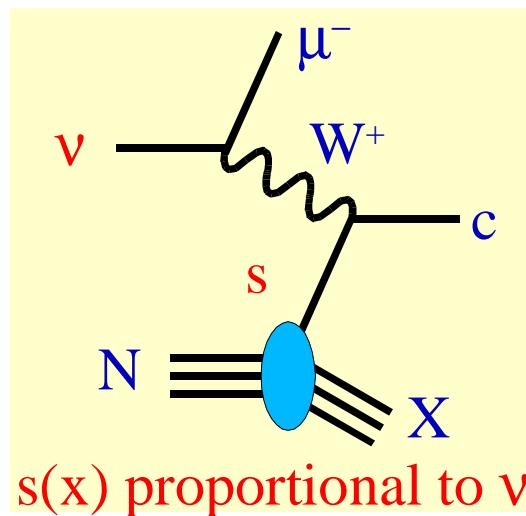
Only di-muon data is
sensitive to $s(x)$!!!

⋮

PRELIMINARY

Idea: fit ν and ν -bar data
separately to approximate
 s and s -bar distributions

Fit ν and $\bar{\nu}$ -bar data separately to approximate s and s -bar



- * Feasible since other data sets are insensitive to $s(x)$
- * Will provide qualitative results
- * Quark number sum rule not satisfied with this approximation

$$\int dx [s(x) - \bar{s}(x)] = 0$$

$$\kappa = \frac{s(x) + \bar{s}(x)}{\bar{u}(x) + \bar{d}(x)}$$

κ	$\nu + \text{anti-}\nu$	ν	$\text{anti-}\nu$
Constrained	0.56	0.50	0.56
Mixed	0.53	0.55	0.59
Free	0.32	0.25	0.37

PRELIMINARY

Compare with Goncharov:

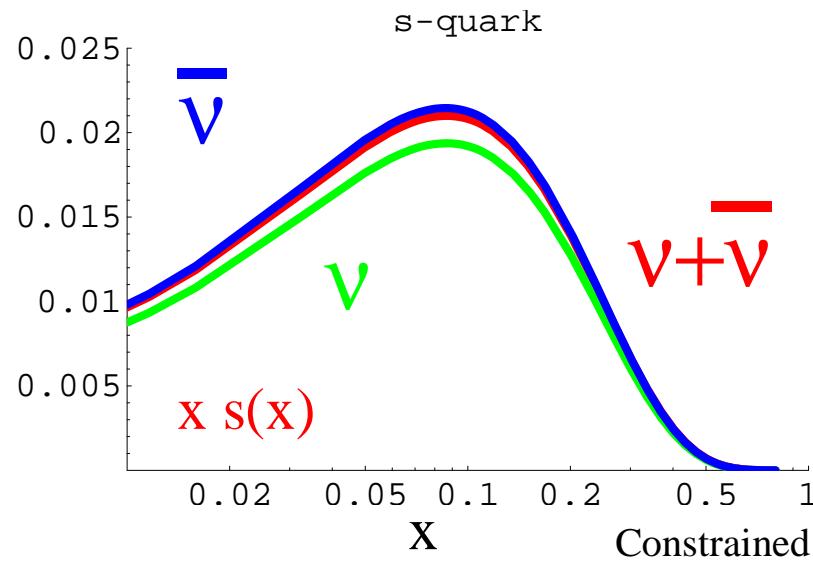
$$\kappa = 0.35 \quad \text{for } \nu$$

$$\bar{\kappa} = 0.41 \quad \text{for } \bar{\nu}$$

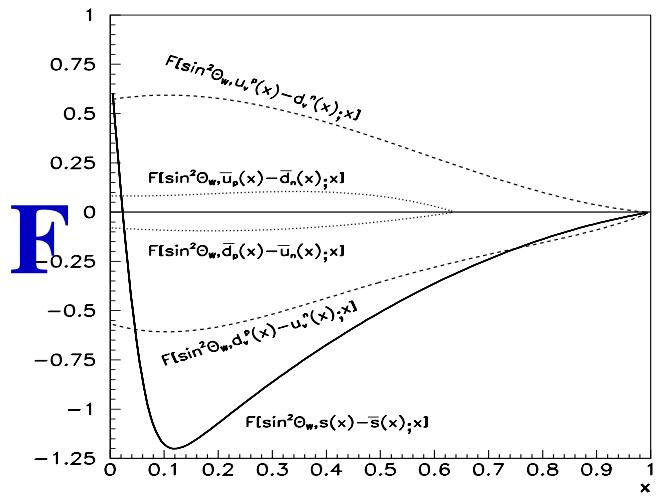
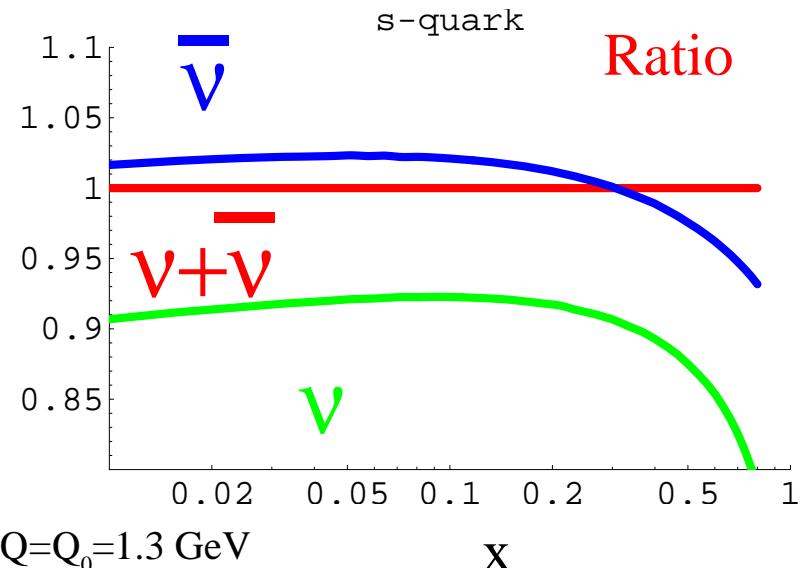
κ value at $Q_0 = 1.3 \text{ GeV}$

M. Goncharov et al., NuTeV Collaboration PRD 64:110226 (2001)

Fit $\bar{\nu}$ and ν -bar data separately



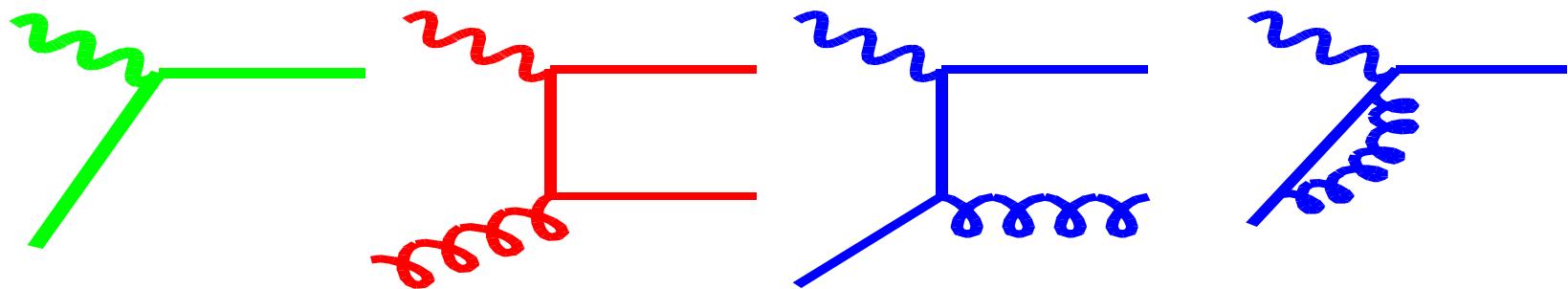
Constrained fit at $Q=Q_0=1.3$ GeV



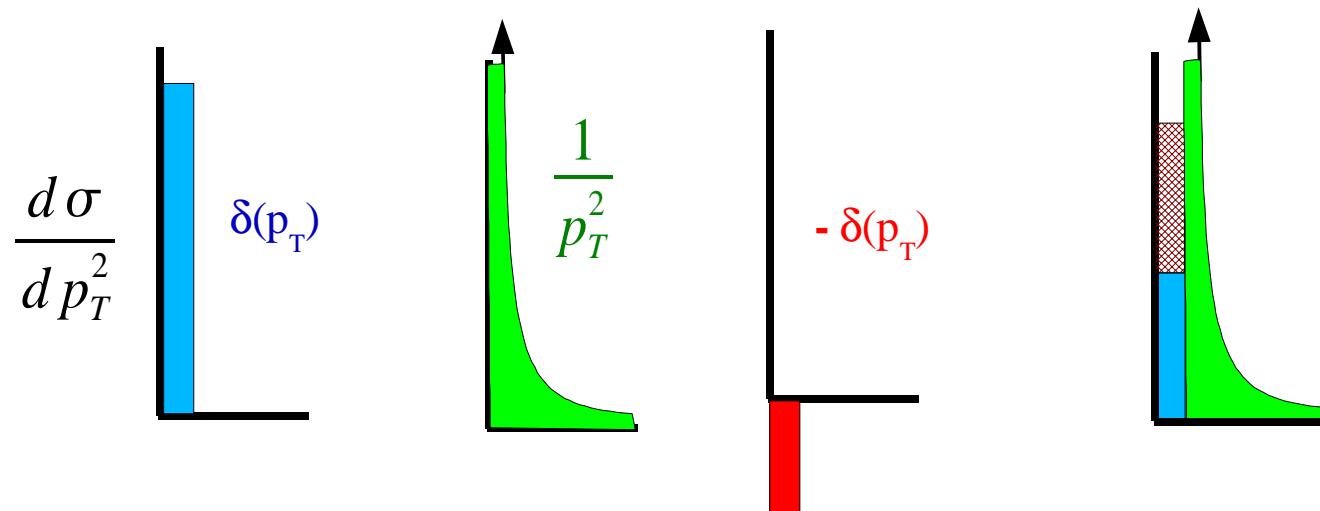
$\bar{\nu}$ data pulls $\bar{s}(x)$ up
 ν data pulls $s(x)$ down

For $s(x) < \bar{s}(x)$
 $\Delta \sin(\theta_w) > 0$
Discrepancy Increases!

NLO Analysis

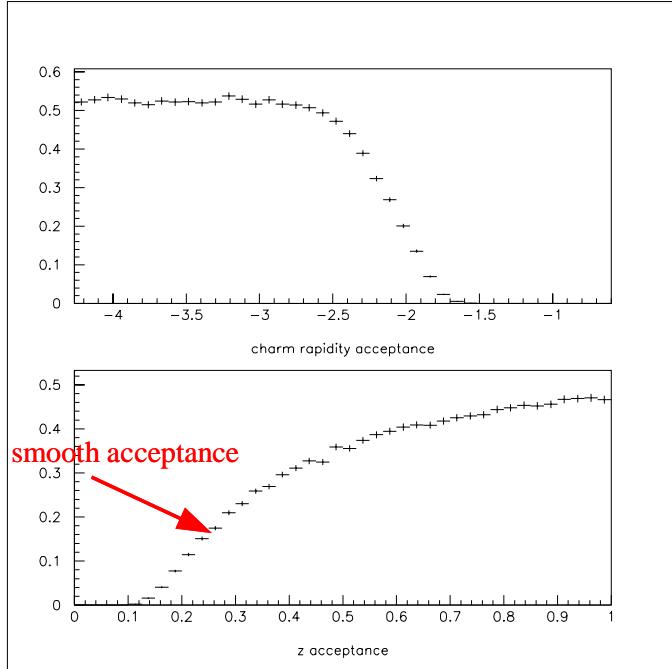


- * Higher order diagrams
- * More differential distributions
- * Encounter distribution functions: $\delta(p_T)$ and $1/(1-x)_+$



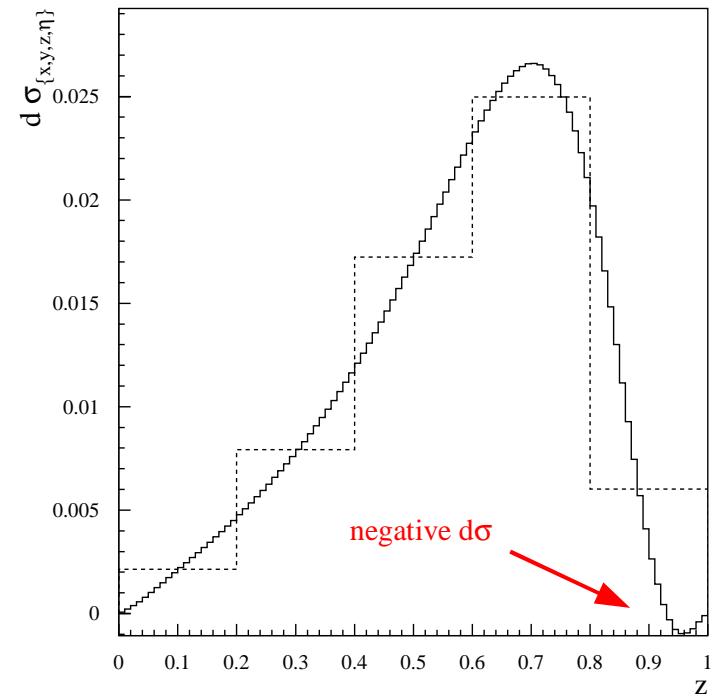
Leading Order + Next-to-Leading Order - Subtraction = Total

Using Experimental Resolution as a Regulator:

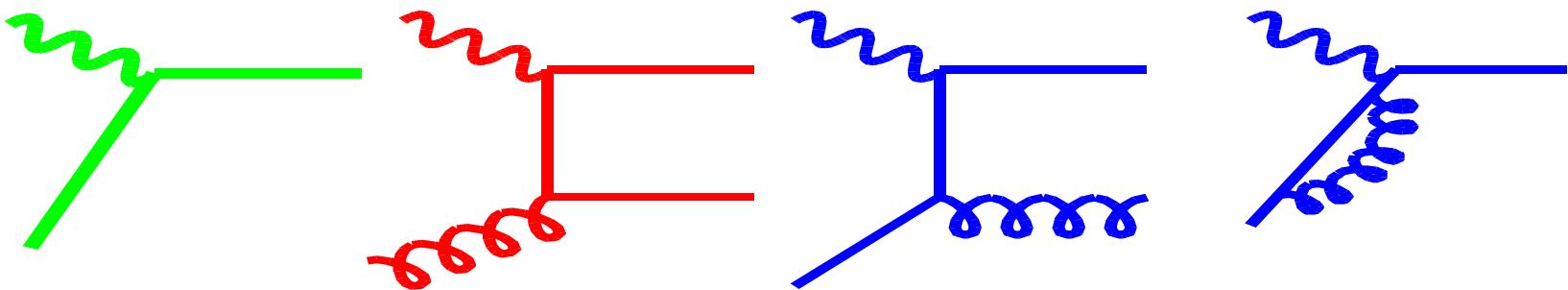


Experimental detector resolution must be larger than the bin size

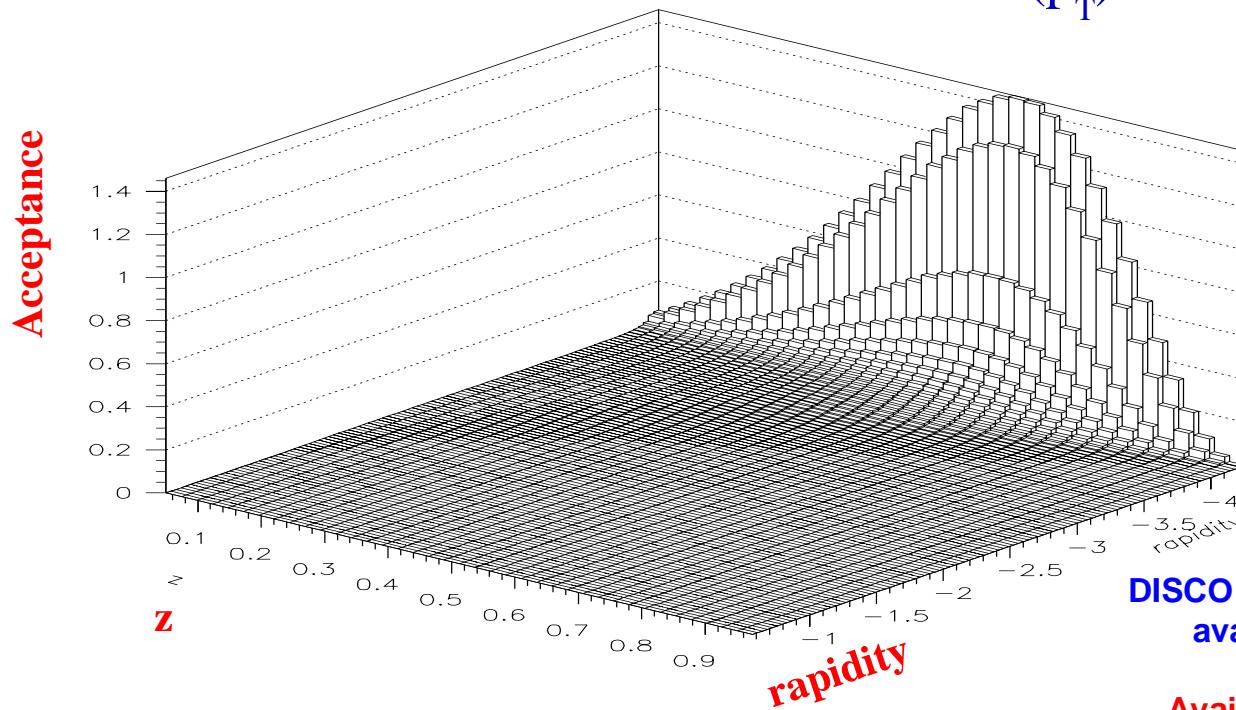
Experimental acceptance must be smooth function of the variables



NLO Analysis



- * Higher order diagrams
- * More differential distributions
- * Encounter distribution functions: $\delta(p_T)$ and $1/(1-x)_+$



Kretzer, Mason, Olness
PRD 65:074010 (2002)

DISCO numerical Fortran program
available for data analysis

Available from Stefan Kretzer

Resummation of soft gluons for massive processes

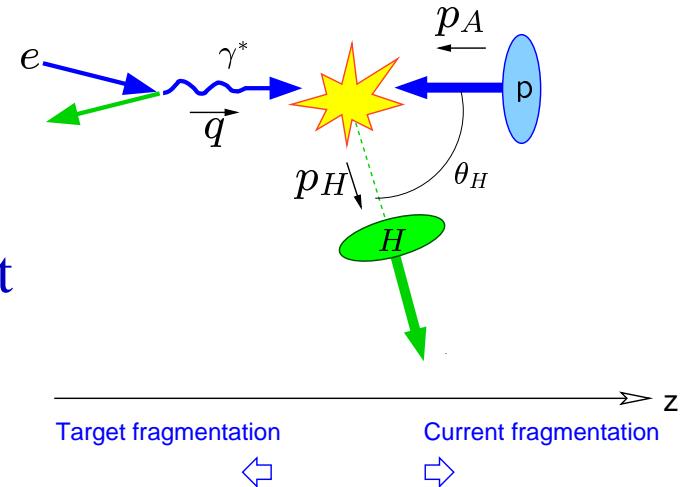
- * Uses CSS Formalism to resum $\text{Log}(q_T/Q)$
- * Uses ACOT Formalism to resum $\text{Log}(M/Q)$

Satisfies appropriate limits:

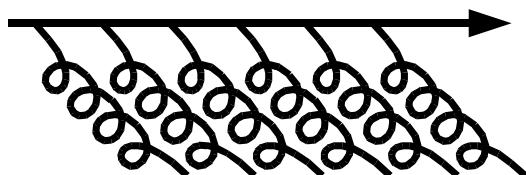
$q_T \rightarrow Q$, obtain usual perturbative result

$M \rightarrow 0$, obtain usual massless result

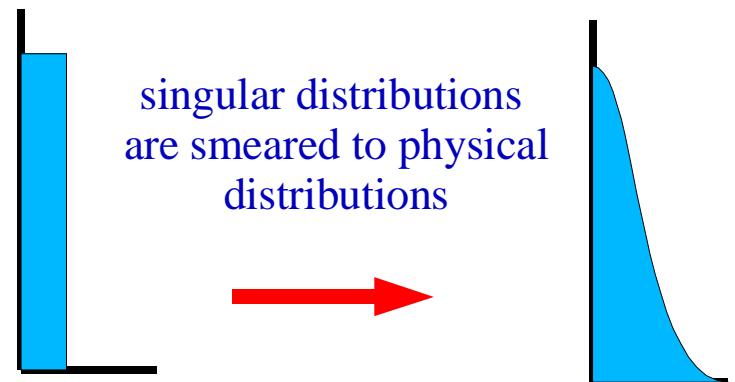
$M, q_T \rightarrow 0$, obtain usual Sudakov form



Theoretical basis for NLO Monte Carlo program
... provides full kinematic description



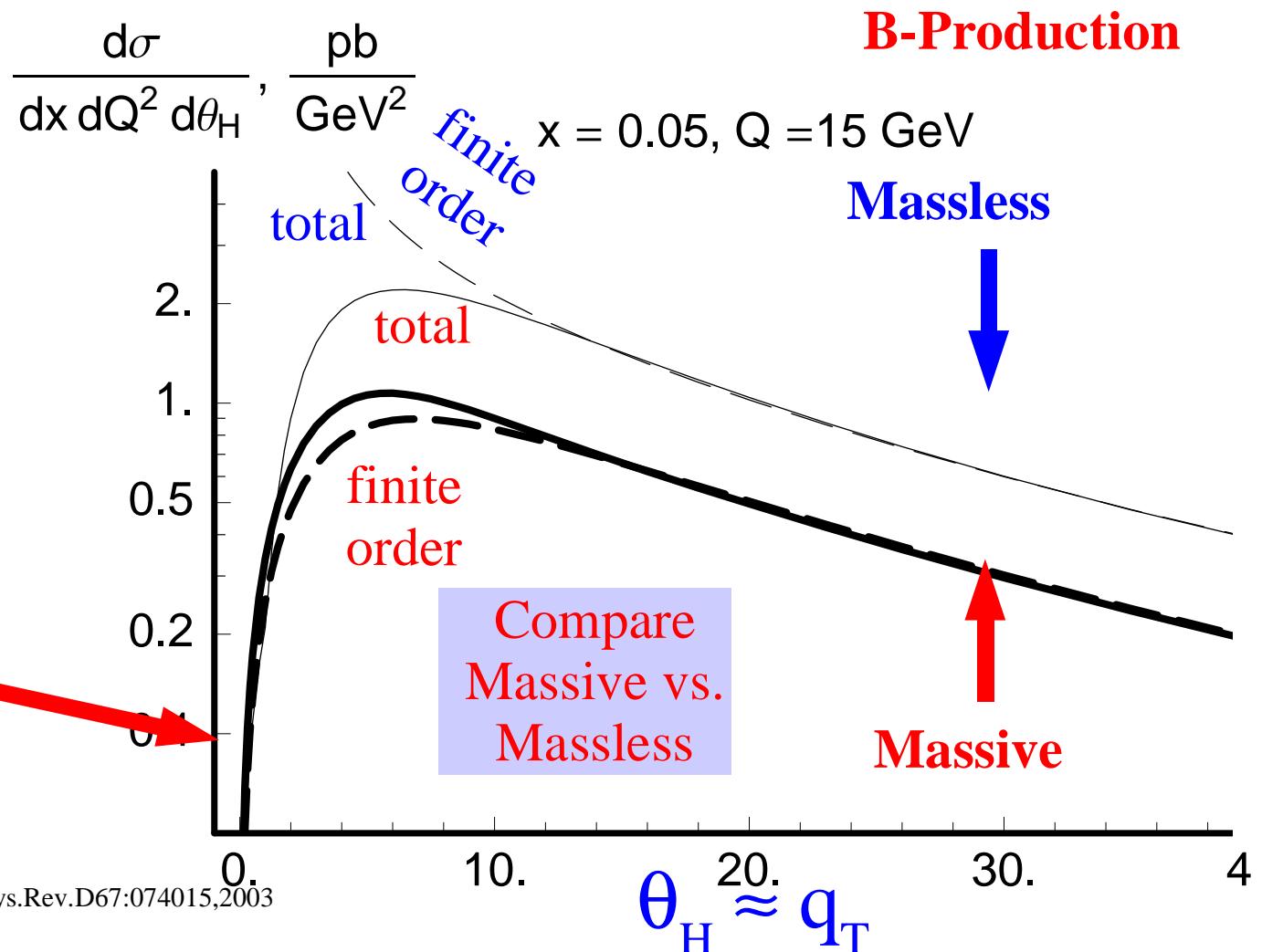
$$= e^{-S}$$



B-Production: Sudakov Resummation of Soft Gluon Radiation

Simplified-ACOT Scheme

$$S_{ba}(b, Q, M_H) = \int \frac{d\mu^2}{\mu^2} \left\{ A(\alpha_s, M_H) \ln \left(\frac{Q^2}{\mu^2} \right) + B(\alpha_s, M_H) \right\} + S_{Non-Pert}$$



Resummation of Transverse Momentum and Mass Logarithms for Heavy Quarks

Fred Olness

LoopFest 2003

14 May 2003

* Di-Muon data incorporated in Global fit:

Provides important information on $s(x)$

Search for "New Physics" signals

Need to consider $s \neq s\text{-bar}$; implications for $\sin^2\theta_W$

This is real progress!!! We now can discriminate!

... for the future ...

* NLO Experimental Dimuon analysis:

NLO Experimental analysis in progress (D. Mason)

NLO code (DISCO) is available (S. Kretzer)

* Resummation of large logarithms:

Resummation of $\log(q_T/Q)$ and $\log(M/Q)$ (P. Nadolsky ...)

Heavy Quark Mass regulates non-perturbative region